UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 16441.7-EL
2. GOVT ACCESSION NO.: AD-A097557
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): A Study of Flicker Noise in MOSFETs
5. TYPE OF REPORT & PERIOD COVERED: Final rept. 16 Mar 80 – 15 Mar 81
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): A. van der Ziel
8. CONTRACT OR GRANT NUMBER(s): DAAG29-79-C-0078
9. PERFORMING ORGANIZATION NAME AND ADDRESS: University of Minnesota, Minneapolis, MN 55455
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
11. CONTROLLING OFFICE NAME AND ADDRESS: U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709
12. REPORT DATE: Mar 81
13. NUMBER OF PAGES: 7
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

LEVEL II

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC SELECTE APR 8 1981 S D C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

NA

18. SUPPLEMENTARY NOTES

The view, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

flicker noise
MOSFETs
pyroelectric films
temperature fluctuation noise
thermal noise
hot electron noise

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Temperature fluctuations, 1/f and g-r noise has been measured and empirically modeled in thin pyroelectric films, in P-implanted buried-channel and weakly inverted MOSFETs. Number and mobility fluctuation models are being used. Re[illegible] is made to papers published or in print.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Final Report

"A Study of Flicker Noise in MOSFETs"

Army Research Office Grant DAAG 29-80-C0078

A. van der Ziel

University of Minnesota
Electrical Engineering Department
Minneapolis, Minnesota 55455

For the period March 1980 - March 1981

1. <u>Review of published work between March 1980 and March 1981.</u>

Van der Ziel and van Vliet (1) published a paper on temperature fluctuation noise in thin pyroelectric films on a thicker substrate. They showed how the white noise of the incoming and emitted radiation is transformed into 1/f temperature fluctuation noise. Here we have a model that directly transforms white noise into 1/f noise without explicit recourse to a distribution of time constants. Unfortunately this 1/f noise is masked by a $1/f^{1/2}$ noise spectrum due to spontaneous temperature fluctuations in the layer and the substrate.

Suh and van der Ziel (2) published measurements on NEC GaAs MESFETs which showed a transition from 1/f to $1/f^2$ noise of the form

$$(A/f)[1 - (2/\pi)\tan^{-1}(\omega\tau_o)]$$

with suitably chosen values for A and τ_o. Such a formula is expected for a superposition of Lorentzian spectra with a distribution

$$g(\tau)d\tau = \frac{d\tau/\tau}{\ln(\tau_1/\tau_o)}$$

for $\tau_o < \tau < \tau_1$ and zero otherwise. The agreement between theoretical considerations and the experimental data is the first proof of the existence of this effect.

Liu, Tufte, van der Ziel, Pai and Larson (3) measured noise in phosphorus-implanted buried-channel MOSFETs at low drain bias. They found some indication of g-r noise at lower frequencies and thermal-like noise at higher frequencies. The g-r bumps were not very pronounced and the noise spectrum could roughly be approximated by a 1/f noise spectrum. The magnitude of this quasi 1/f noise was close to the 1/f noise expected from the oxide itself and resulted in a relatively low value of the Hooge parameter α_H.

Liu and van der Ziel (4) measured high-frequency noise in weakly inverted MOSFETs. The noise is thermal noise of the form

$$S_{I_d}(f) = (2/3)\ 4kT\ g_m\ ,$$

where g_m is the transconductance, and not shot noise of the current I_d.

2. <u>Review of papers in the press</u>.

Park, van der Ziel and Liu (5) measured 1/f noise in MOSFETs at low drain voltages and evaluated the effective trap density at the Fermi level, $N_T(E_f)_{eff}$, of the number fluctuation model and the Hooge parameter, α_H, of the mobility fluctuation model. Both parameters had reasonable values, so that either theory could be viable. It should be noted that the value of α_H was considerably smaller than the value 2×10^{-3} originally proposed by Hooge.

Park, van der Ziel, Zijlstra and Liu (6) discriminated between the number fluctuation and the mobility fluctuation models in MOSFETs by measuring $S_{I_d}(f)$ as a function of the drain voltage V_d, where V_d varied from low values through saturation. In the first model $S_{I_d}(f)$ should monotonically increase with V_d until saturation, whereas in the other model $S_{I_d}(f)$ should show peak well before saturation. This is due to the fact that $N_T(E_f)_{eff}$ should be independent of the field, whereas the Hooge parameter α_H decreases strongly with increasing field. Some devices were found to agree with the one model, whereas others agreed with the other.

In a subsequent paper van der Ziel, Zijlstra and Park (7) calculated the integrals proposed in the previous paper and so replaced the qualitative discussion by a quantitative one, thus putting that theory on a firm basis. The effects of the high-field mobility and the field-dependent α_H greatly reduce the noise near saturation, not only in MOSFETs, but even more so in JFETs. This might make it possible to explain the absence of 1/f noise in low-noise JFETs by a mobility fluctuation noise with a low-field value of α_H of the order of 10^{-6}.

Suh and van der Ziel (8) applied the discrimination approach to NEC GaAs MESFETs operating in the 1/f part of the spectrum. Both models could qualitatively explain the data, but the mobility fluctuation model might be more likely, since it operates at lower electric fields.

Van der Ziel (9) calculated the thermal noise in the semiconductor regime of double-injection space-charge-limited solid-state diodes by a new method that removes a difficulty in an earlier theory developed under a previous ARO contract.

Kim and van der Ziel (10) measured hot electron noise and g-r noise in short-channel MOSFETs as a function of the gate bias and of temperature. There is g-r noise due to partly ionized donors at lower temperatures and hot electron noise at higher temperatures. The g-r noise masks the hot electron noise below 130°K.

Kim, van der Ziel and Liu (11) measured hot electron noise effects in buried channel MOSFETs. They found noise that increased with decreasing temperature and also increased with increasing values of $(V_g - V_T)$.

3. Outlook for future work.

We did measurements on various MOSFET device parameters, such as surface mobility, $N_T(E_f)_{eff}$ and α_H, on oxide thickness. The results showed complicated dependences. This problem requires substantial looking into.

We did noise measurements on JFETs and found 1/f noise in some units. Hooge's parameter α_H had a moderate value of 5×10^{-5} at low fields. We found that $S_{I_d}(f)$ does not vary as V_d^2 at low fields, as expected theoretically. We expect to look into this problem further; especially we want to investigate whether the theory of reference (7) can explain the data.

We have made measurements of 1/f noise in GaAs current limiters as a function of the device voltage V_d. The noise varies as V_d^2 at low values of V_d, as expected theoretically, passes through a maximum before saturation and then levels off to a constant value at saturation. The 1/f noise at saturation is so large that one has to go to the GHz frequency range to see hot electron noise. We will do considerably more work on this problem.

We are measuring 1/f noise and thermal noise in ballistic GaAs diodes. The devices have a low internal resistance and the low-frequency noise is difficult to measure against a pick-up noise background. The 1/f noise, if any, seems to be relatively small. The thermal noise is of the order of the thermal noise of the a.c. conductance. It might be possible to use thermal noise measurements in order to discriminate between ballistic and space-charge-limited operation.

Amberiadis (12) measured 1/f noise in gate-controlled ion-implanted epitaxial resistors under another contract. He found a very considerable increase in noise at the onset of strong inversion. If the noise were due to number fluctuations, the noise would decrease strongly because the holes no longer interact with the surface at strong inversion. If the noise were due to bulk mobility fluctuations, there would be a slight increase in the noise due to the small increase in resistance. The increase in noise by more than two orders of magnitude can only be explained as surface-controlled mobility fluctuations as proposed earlier by Jindal and van der Ziel under a previous grant (13). This model assumes that the fluctuating occupancy of the oxide traps modulates the surface potential, and this, in turn, modulates the surface scattering of the carriers and hence the mobility. We believe that this may be of considerable importance for understanding 1/f noise in semiconductors in general and semiconductor devices such as MOSFETs in particular.

4. References.

1. A. van der Ziel and K. M. van Vliet, Temperature fluctuation noise in thin pyroelectric films, Ferroelectrics, 28, 365, 1980.
2. C. H. Suh and A. van der Ziel, A noise spectrum described by a distribution of time constants, Appl. Phys. Lett., 37, 365, 1980.
3. S. T. Liu, O. N. Tufte, A. van der Ziel, S. Y. Pai and W. Larson, Noise in phosphorus-implanted buried channel MOS transistors, Solid State Electron., 23, 1195, 1980.
4. S. T. Liu and A. van der Ziel, High-frequency noise in weakly inverted MOS transistors, Appl. Phys. Lett., 37, 950, 1980.
5. H. S. Park, A. van der Ziel and S. T. Liu, Comparison of two 1/f noise models in MOSFETs, Solid State Electron., 24, 1981, in the press.
6. H. S. Park, A. van der Ziel, R. J. J. Zijlstra and S. T. Liu, Discrimination between two 1/f noise models in MOSFETs, J. Appl. Phys., 52, 1981, in the press.
7. A. van der Ziel, R. J. J. Zijlstra and H. S. Park, Discrimination between 1/f noise models in JFETs and MOSFETs, numerical results, J. Appl. Phys., 52, 1981, in the press.
8. C. H. Suh and A. van der Ziel, 1/f noise in GaAs MESFETs, Solid State Electron., 24, 1981, in the press.
9. A. van der Ziel, Thermal noise in the semiconductor regime of double-injection space-charge-limited solid-state diodes, Physica B, 1981, in the press.

10. S. K. Kim and A. van der Ziel, Hot electron noise and g-r noise in short-channel JFETs, Solid State Electron., <u>24</u>, 1981, in the press.

11. S. K. Kim, A. van der Ziel and S. T. Liu, Hot electron noise effects in buried channel MOSFETs, Solid State Electron., <u>24</u>, 1981, in the press.

12. K. Amberiadis, 1/f noise in gate-controlled implanted resistors, 6-th Conference on Noise in Physical Systems, Washington, D.C., April 1981, to be published.

13. R. P. Jindal, Ph.D. thesis, University of Minnesota, 1981; see also A. van der Ziel, 1/f noise in solid state devices, Advances in Electronics and Electron Physics, <u>49</u>, 225, 1979 (review paper).

ATE

LMED

8